IPST Technical Paper Series Number 515

Assessment of the Influence of Paper Formation on the Fluorescence Contribution to Brightness

Y.Y. Kulikova, M.K. Schaepe, and W.B. Robbins

February 1994

Presented at
Inter-Society Color Council Meeting
February 22, 1994
Williamsburg, VA

Assessment of the Influence of Paper Formation on the Fluorescence Contribution to Brightness

Yana Y. Kulikova, Michael K. Schaepe, and Wayne B. Robbins
Institute of Paper Science and Technology
Atlanta, GA 30318

Summary

Paper was produced under controlled conditions with a range of resultant formation and a constant level of fluorescent dye. Brightness and whiteness and the fluorescent contribution to brightness or whiteness were measured by directional or diffuse illumination. Brightness, whiteness, and fluorescence were evaluated as the illuminated sample aperture diameter was varied from a maximum of 12.7 mm to a minimum of 6.0 mm.

It appears that fluorescent dyes partially mask formation-induced optical variations at reduced illuminated sample aperture diameters. This suggests possible improved subjective appearance of papers containing fluorescent dyes beyond that expected solely on the basis of paper formation.

Introduction

The influence of paper formation on printability and paper coating performance is well documented (1, 2). Calendering or pressing strategies for a number of different paper grades have been proposed and implemented to minimize these variations in base sheet structure (2, 3, 4, 5, 6). One result of calendering is a reduction in the variation of Z-directional nonuniformities or surface roughness. (2, 7). The smoother sheets are subsequently more receptive to uniform ink coverage (4, 8, 9). This process can also diminish the overall variation of apparent density of the paper, generally resulting in reduced formation scale variations in coating-basesheet interactions. Despite these documented quality improvements, these engineering approaches fail to address the root source cause of variation, which is variety of the size and apparent density of fiber flocs within a given sheet. This is further aggravated by the fact that when paper is subjectively evaluated, both printed and unprinted areas are observed. A number of measures are commonly used to evaluate printed images. A few include sharpness of image, dot gain, and mottle of numerous types (10). One of the more obvious subjective measures of unprinted appearance is the relative variation in reflected light, brightness or whiteness, which results from poorly formed sheets. This is easily traced back to formation scale variations in fiber floc size and apparent density. However, direct observation of brightness for many premium grades of uncoated or coated paper is confounded by the relatively common use of fluorescent dyes for brightness enhancement. From a subjective appearance perspective, it is difficult to determine to what degree light or dark areas in the sheet, which are normally attributed to variations in fiber floc mass density, are masked by fluorescent dyes adhering to the fibers. It is further complicated by the presence of inorganic fillers which will not be considered in this paper. Therefore, understanding the relationship of paper formation and the fluorescence contribution to paper brightness is an important element in providing a test regimen which describes subjective paper nonuniformity appearance.

Discussed herein are the results of an experiment designed to understand the overall magnitude of fluorescence variability as it relates to paper formation.

Experimental

The general experimental approach involved initial production of a range of papers exhibiting significantly different formation. Brightness or whiteness and the fluorescent contribution to brightness or whiteness were measured by both directional and diffuse illumination. Brightness, whiteness, and fluorescence were then evaluated as the sample aperture was varied from a maximum of 12.7 mm to a minimum of 6.0 mm.

a) Paper Production

The paper was produced using a slow speed web former located at the Institute of Paper Science and Technology. The stock and machine conditions are shown in Table I. Formation was altered from good to poor using successively increasing addition levels of retention aid at the web former fan pump. Fluorescence was held constant by maintaining a constant concentration of fluorescent dye in the paper machine stock chest.

b) Formation Measurements

Formation was measured on representative samples from each of the conditions using samples 8 x 11 inches in size. Measurements were performed using an M/K, model FT200 Microformation Tester (11).

c) Directional Brightness/Fluorescence

Directional brightness was measured according to the TAPPI T-452 om-92 test method using a Technidyne S-4 Brightimeter. Non-reflective aperture blanks were manufactured to reduce the existing 12.7 mm sample aperture to achieve additional aperture diameters to a minimum of 6 mm. Instrument noise was defined as two times the standard deviation of 20 brightness measurements obtained 10 minutes apart using opal glass standards. This procedure was used for opal glasses with brightness values in the approximate range of the trial paper including and excluding fluorescence for each of the sample apertures. The resulting detection limits were consistent with experience gained in normal operation of the equipment.

Portions of each of the representative paper formation conditions were cut into 2x2½ inch sheets. Twenty representative samples of each formation condition were created by stacking 2x2½ inch sheets to a thickness so that doubling the number of sheets in the sample resulted in no measurable difference in brightness (12, 13).

Brightness, including and excluding fluorescence, was measured on 5 sheets within each of the 20 samples for each of the sample aperture diameters.

c) Diffuse Whiteness/Fluorescence

Diffuse whiteness was measured according to the method described in ISO 2469-1977 using a DataColor Elrepho 2000 instrument. Non reflective blanks were manufactured to result in sample aperture diameters ranging from a maximum of 12 mm to a minimum of 6 mm. Detection limits were determined in the manner discussed previously by utilizing a similar strategy of using the glass standards approximating whiteness values including and excluding fluorescent contribution at both sample aperture diameters. The same 20 representative paper samples discussed above for each formation condition were evaluated for whiteness, including and excluding fluorescence, by evaluating 5 sheets within each sample for each of the sample aperture diameters.

Results and Discussion

The principal reason the paper used in this experiment was produced at the Institute was to ensure control of the wide variety of process control variables in the papermaking process which have the potential to confound the results. Some of these include variation of the ratio of hardwood and softwood content, MD/CD ratio, basis weight, and fluorescent dye content. Web former conditions were held constant so that the only variable used to manipulate formation was the polymeric retention aid dosage. The increased concentration of this chemical had no measurable impact on the fluorescent contribution as demonstrated by data discussed below.

A range of papers was produced for possible measurement, even though only the extremes were evaluated in the experimental design. Photographs of the light transmitted through the formation extremes of the papers produced are shown in Figures A and B. The specific web former trial condition designations for these papers are "B" for the best formation and "F" for the worst formation.

Paper from all of the trial conditions was evaluated using an optical transmittance formation measurement apparatus, as noted in the Experimental section. Results of these measurements are shown in Table II. The reported Formation Index represents the ratio of the amplitude of a running mean of optical densities and the number of discretely different optical densities measured in a fixed scanning cycle. Thus, sheets exhibiting better formation will show higher amplitudes, a lower number of different optical densities, and, therefore higher Formation Indices. The trend of Formation Indices is consistent with the photographs shown in Figures A and B.

The detection limit data is shown in Table III. The 2 σ limits for instrument noise for the directional brightness instrument are clearly higher than for the diffuse whiteness instrument. A combination of the instrument readout and apparent stability of the diffuse instrument result in calculations of baseline noise that are not useful if strictly interpreted. The tungsten lamp source used in the directional instrument is the likely primary source of its variability. However, for the purpose of this study, the more significant question is what portion of the COV is attributable to instrument noise at the approximate level of brightness or whiteness relative to that of the test paper at each sample aperture diameter.

Extreme conditions of formation and sample aperture diameter were chosen as independent variables in a simple 2x2 experimental design. Brightness and whiteness data including and excluding the fluorescent contribution for this experimental design are shown in Tables IV and V, respectively. The resultant fluorescent contribution to brightness or whiteness, as determined by difference, is also summarized in these tables.

The data used in the calculation of COV for the directional fluorescent contribution to brightness is nominally at or below the limit of detection of the instrument. A decision was made to continue the analysis, despite the marginal significance of this data, with the objective of providing supporting evidence for the diffuse whiteness measurements. The data used in the calculation of COV for the diffuse fluorescent contribution to whiteness exceeds the defined limit of detection of that instrument. Therefore, the conclusions drawn from interpretation of this data are primarily based upon diffuse whiteness results.

The fluorescence data is more easily visualized in Figures C and D, where the fluorescence COV data is illustrated both with respect to brightness and whiteness, respectively, as a function of sample aperture diameter and paper formation. In both figures, the largest sample aperture and best formation sample is shown in the lower right corner.

Referring to Figure C, the directional brightness data, the lower right corner has the lowest coefficient of variation in the design. This is predictable due to the large area over which the signal is effectively averaged, and the relative uniformity of this paper surface. Moving up the formation axis at the same sample aperture diameter, the COV doubles as formation degrades. Similarly, moving from the lower right corner of the design across to the 6 mm sample aperture diameter, the COV also doubles. An increase in COV may have been anticipated due to the reduced area over which surface defects are effectively averaged. Finally, moving from the lower right corner of the design diagonally to the condition representing both poor formation and 6 mm aperture size, an increase in COV is observed, but the increase in COV is small compared on a relative basis to COVs at either the good formation and 6 mm sample aperture size, or poor formation with 12.7 mm aperture size.

The data shown in Figure D for the diffuse measurements illustrate the same trends as those shown in Figure C. It is significant that although the absolute magnitude of the COVs is different, they increase by nearly the same relative amounts as observed for the directional brightness data. Therefore, the fluorescent contribution COV data are mutually supportive.

With these tentative observations, it is appropriate to examine both the directional and diffuse brightness and whiteness data including and excluding fluorescence to determine if there are trends similar to those discussed above. Similarity, or lack thereof, is the determining factor of the relevance of the fluorescence data.

The COV data for the directional measurements including and excluding fluorescence are illustrated in Figures E and F. While the COV increases upon moving from good formation to poor formation at both aperture diameters, only the poor formation sample COV increases in magnitude upon moving to a smaller aperture diameter.

The COV data for the diffuse whiteness measurements including and excluding fluorescence are illustrated in Figures G and H, respectively. The whiteness including fluorescence COV data in Figure G shows a twofold increase moving from good to poor paper formation at both the 12 mm and 6 mm aperture diameters. Little or no increase in COV is observed at either formation by reducing aperture size. The whiteness excluding fluorescence contribution data shown in Figure H is similar, but more complementary to the fluorescence results shown in Figure D. The COV doubles moving from good to poor formation at the 12 mm aperture size, and again moving from the 12 mm to the 6 mm aperture for the good formation paper. It is interesting that an approximation of the floc size in the formation paper is 3 mm, 50% of the sample aperture diameter. An equally interesting observation is that the approximate floc size of the poor formation paper is 6 mm, approximately 50% of the 12 mm sample aperture diameter. Finally, the COV also increased by approximately 50% by moving from good to poor formation at the 6 mm aperture size.

Based upon the trends discussed above, it is appropriate to expand upon similarities and differences in the data. The initial fluorescent contribution to brightness data was consistent between both the directional and diffuse instruments. More specifically, the general trends and relative magnitude of differences of COV as paper formation varies, or as aperture size varies, are the same. The absolute value of COV is different, but this was expected both by the baseline instrument noise and the relative magnitude of the fluorescent contribution. Unfortunately, although the trends in the COV data for directional brightness including and excluding the fluorescent component appear somewhat similar to the fluorescent contribution trends, definitive conclusions appear obscured by instrument noise. Conversely, the diffuse whiteness data including the fluorescent component shown in Figure G appears to be an approximation of the sum of its components. This is most easily observed in the trends of moving from large to small aperture at poor formation or moving from good formation to poor formation at the 6 mm aperture size. The differences in COV for these trends in Figure G appear to be a combination of the differences shown in Figures H and D. The differences in Figure H appear larger in magnitude than those in Figure D.

Since the samples were layered in a manner so that they were not translucent, it is speculated that the differences shown in Figure H arise primarily from differences in surface roughness, resulting in variability of the light reflected back to the instrument detector. These roughness differences are expected due to differences in fiber floc mass density and thickness within the sheet, as well as the overall diameter of the flocs.

The same trends are observed for the fluorescent data shown in Figure D, but are smaller for the poorly formed paper at small aperture sizes. This suggests that surface roughness plays a smaller role in measured fluorescence when aperture size decreases. It is speculated that the fluorescent dye concentration may not be evenly distributed across all fibers, but may be disproportionately concentrated in local low basis weight areas where fiber fines represent a higher percentage of the measured surface, and a higher concentration of fluorescent dye might be expected due to a higher reactive surface area. This nonuniformity with respect to fluorescent dye concentration diminishes the rate of increase of COV in poorly formed papers as aperture size is reduced. Therefore, formation effects resulting from surface roughness, which are observed in Figure H are masked and result in diminished effects of formation-induced roughness observed in Figure G.

At the outset of this paper it was implied that a void exists between subjective appearance evaluations and scientific data that correlates to those evaluations. The data presented herein suggest technical efforts be focused toward understanding the relationship between aperture size and our ability to subjectively perceive defects. The data also suggest that fluorescent dyes partially mask formation-induced optical variations at a 6 mm aperture diameter, but not at the North American Paper Industry standard aperture diameter of 12.7 mm. Stated differently, it is possible that we may not be routinely measuring what we subjectively observe. Furthermore, the magnitude of the COVs in Figure H suggest an improved ability to assess formation related whiteness variation at a reduced aperture size. Further definition of an aperture size that corresponds to our ability to subjectively evaluate appearance would accelerate process development efforts aimed at improving and controlling subjective appearance of paper.

The substantive conclusions and questions which arise from this data are not related to the noise level of an instrument, or whether the fluorescent component is measured using directional or diffuse sample illumination. An observation was made that whiteness values including the fluorescent contribution appear to be a combination of its parts, the component excluding fluorescence, and its fluorescent component. This observation is not startling, but it is significant since it lends credibility to the hypothesis of nonuniform distribution of the fluorescent component compared to fiber floc distribution or formation of the paper. These trends suggest a leveling of the COV of the fluorescent component with diminishing aperture sizes, resulting in possible improved subjective appearance of papers beyond that expected on the basis of paper formation.

References

1. Novak, G., Malesic, I. Coating Base Paper as One of the Most Important Factors for the Quality of Coated Papers. Papier 46. 109-115. (1992)
2. Madsen, V.H., Aneliunas, A.E. Effect of Formation on Print Quality. TAPPI 51. 309-314. (1968)
3. Hunger, G.K. Influence of Calendering on sheet and Coating Densification and on Final Printability. TAPPI 50. 372-379. (1967)
4. Eckert, K. Gloss and Smoothness Generation - Plant Experiences with Groundwood-Containing Uncoated Super-Calendered (SC) Papers. Papierfabr. 121. 87-88, 90-94. (1993)
5. Nehring, H. Use of Polyelectrolytes in the Manufacture of Uncoated Gravure Papers and coating Raw Stock with a High Groundwood Content. Papierfabr. 99. 48-51. (1971)
6. Brecht, W., Muller, G. Tests Performed with a Gloss Calender. TAPPI 51. 61-66A. (1968)
7. Karttunen, S., Perila, O. The Printability of Gravure Papers. IV. On the Optimum Paper Quality. Graphic Arts Res. Inst. Finland Research Report no. 13. 8 pp. (1966)
8. Dunfield, L.G., McDonald, J.D., Gratton, M.F., Crotogino, R.H. Gravure Printability of Steam-Treated Machine-Calendered Newsprint. J. Pulp Paper Sci. 12. J31-38. (1986)
9. Charbonnier, M. Influence of Paper in Printing. EUCEPA Conf. Paper Printability 14. Paper No. 34. 26 pp. (1971)
10. Parsons, C.L., Abson, P.L. Predicting Print Gloss Mottle. TAPPI Printing Reprography/Test. Conf. Papers. 25-28. (1977)
11. M/K Systems, Inc. Microformation Tester Operating Manual, Model FT200 (OJKD) 1985.
12. Sampling and Accepting a single Lot of Paper, Paperboard, Containerboard, or Related Product. TAPPI Test Methods. T 400 om-90. (1993)
13. Brightness of Pulp, Paper, and Paperboard. TAPPI Test Methods. T 452 om-92. (1993)

List of Tables

Table I

Slow Speed Web Former Trial Conditions

Machine Trim width	12 inches
Machine Speed	10 ft/min
Basis Weight	31 lb/3000 sq ft
Furnish	55% mixed Southern gum and oak
	45% Southern pine
Headbox	Freeness (CSF) 557 ml
	Consistency 0.85%
Retention Aid	Nalco® 752 (cationic)
	point of addition: fan pump
	levels of addition: 0.5-15.0 lb/ton
Fluorescent Dye	Tinopal PT®
	point of addition: stock chest
	level of addition: 14 lbs/ton
MD/CD Ratio	1.3/1

Table II

Formation Index Summary of Web Former Trial Papers

Condition	Formation Index	Retention Aid Dosage (lbs/ton)
A	5.44	0.00
B	6.65	0.50
C	4.48	1.25
D	4.58	3.00
E	2.53	8.00
F	0.59	15.00

Table III

Instrument Detection Limit Data

TECHNIDYNE S-4 DIRECTIONAL BRIGHTNESS

		Sample Aperture Diameter (mm)	
Standard		6	12
a	Avg*	87.86	87.84
	σ	0.05	0.06
	2σ	0.10	0.12
b	Avg*	80.00	79.78
	σ	0.17	0.12
	2σ	0.34	0.24

DATACOLOR ELREPHO 2000 DIFFUSE WHITENESS

		Sample Aperture Diameter (mm)	
Standard		6	12
e	Avg*	95.0	95.0
	σ	0.0	0.0
	2σ	0.0	0.0
b	Avg*	70.0	68.0
	σ	0.0	0.0
	2σ	0.0	0.0

* Average of 20 readings taken 10 minutes apart

Table IV

Directional Brightness Data Summary

WEB FORMER TRIAL CONDITION - B

			Sample Aperture Diameter (mm)	
			6	12
Brightness	Including Fluorescence	Avg*	88.38	89.56
		σ	0.12	0.13
		COV	0.14	0.15
	Excluding Fluorescence	Avg*	82.06	82.70
		σ	0.12	0.13
		COV	0.15	0.16
	Fluorescent Component	Avg*	6.32	6.86
		σ	0.13	0.07
		COV	2.06	1.02

WEB FORMER TRIAL CONDITION - F

			Sample Aperture Diameter (mm)	
			6	12
Brightness	Including Fluorescence	Avg*	87.10	88.44
		σ	0.29	0.23
		COV	0.33	0.26
	Excluding Fluorescence	Avg*	80.81	81.61
		σ	0.25	0.19
		COV	0.31	0.23
	Fluorescent Component	Avg*	6.29	6.82
		σ	0.16	0.15
		COV	2.54	2.20

* Average of 5 readings each of 20 samples

Table V

Diffuse Whiteness Data Summary

WEB FORMER TRIAL CONDITION - B

			Sample Aperture Diameter (mm)	
			6	12
Brightness	Including Fluorescence	Avg*	113.9	113
		σ	0.2	0.1
		COV	0.2	0.1
	Excluding Fluorescence	Avg*	69.8	68.0
		σ	0.3	0.2
		COV	0.4	0.3
	Fluorescent Component	Avg*	44.1	45.0
		σ	0.3	0.2
		COV	0.7	0.4

WEB FORMER TRIAL CONDITION - F

			Sample Aperture Diameter (mm)	
			6	12
Brightness	Including Fluorescence	Avg*	112.1	110.8
		σ	0.3	0.3
		COV	0.3	0.3
	Excluding Fluorescence	Avg*	67.4	66.2
		σ	0.4	0.3
		COV	0.6	0.4
	Fluorescent Component	Avg*	44.7	44.6
		σ	0.3	0.3
		COV	0.7	0.7

*Average of 5 readings each of 20 samples

List of Figures

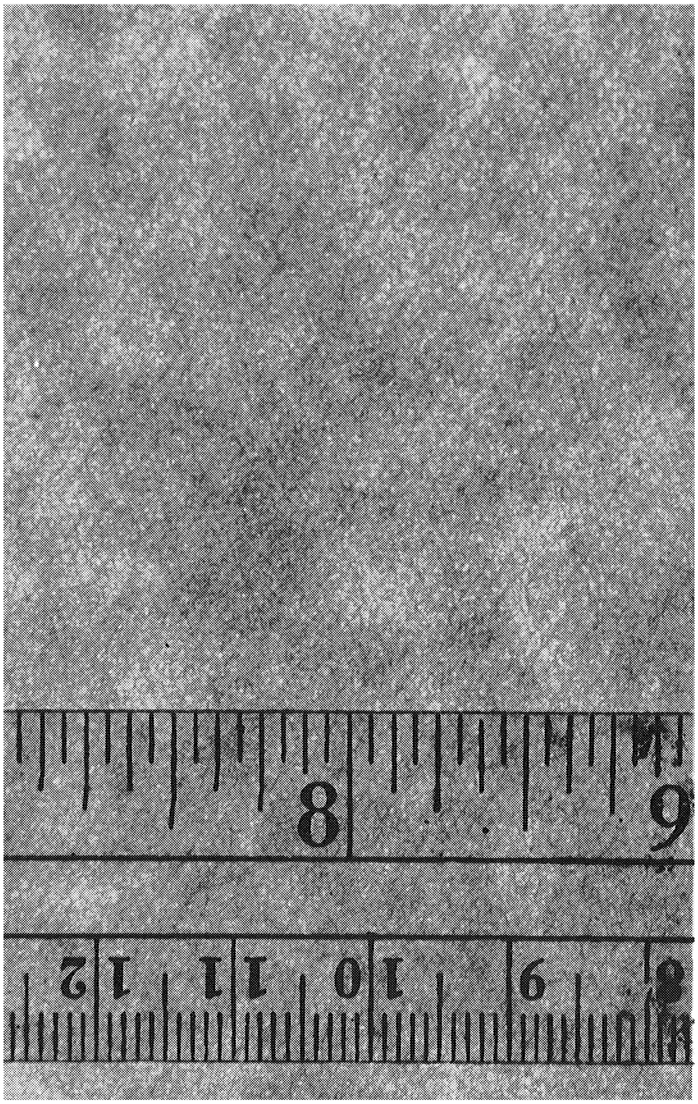

Figure A

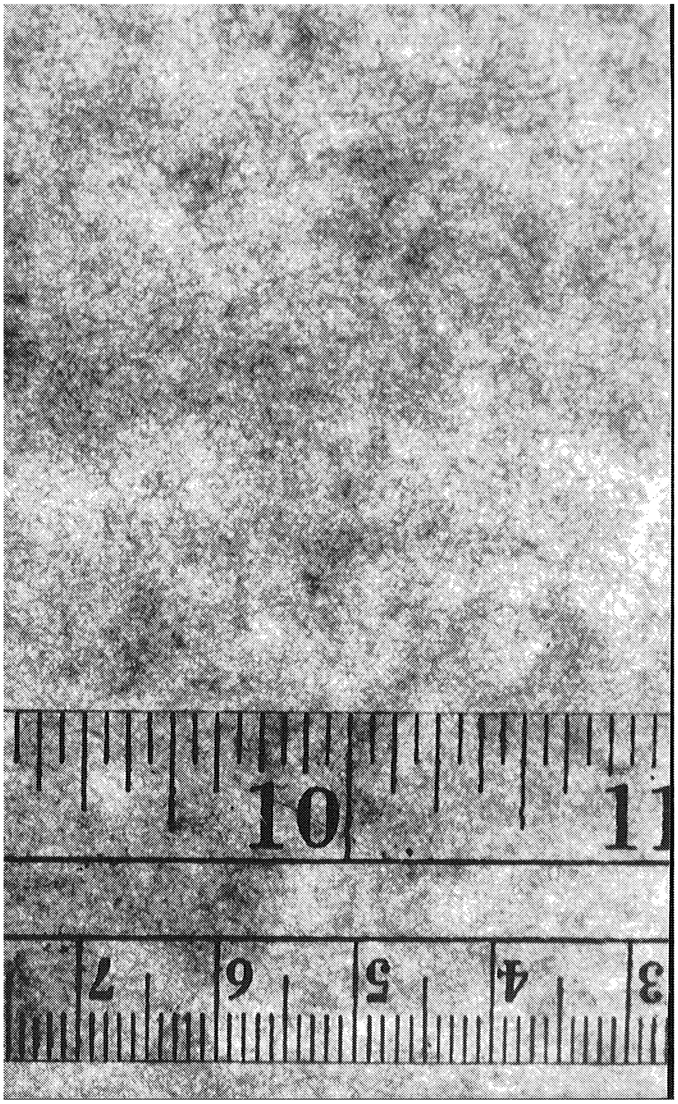

Figure B

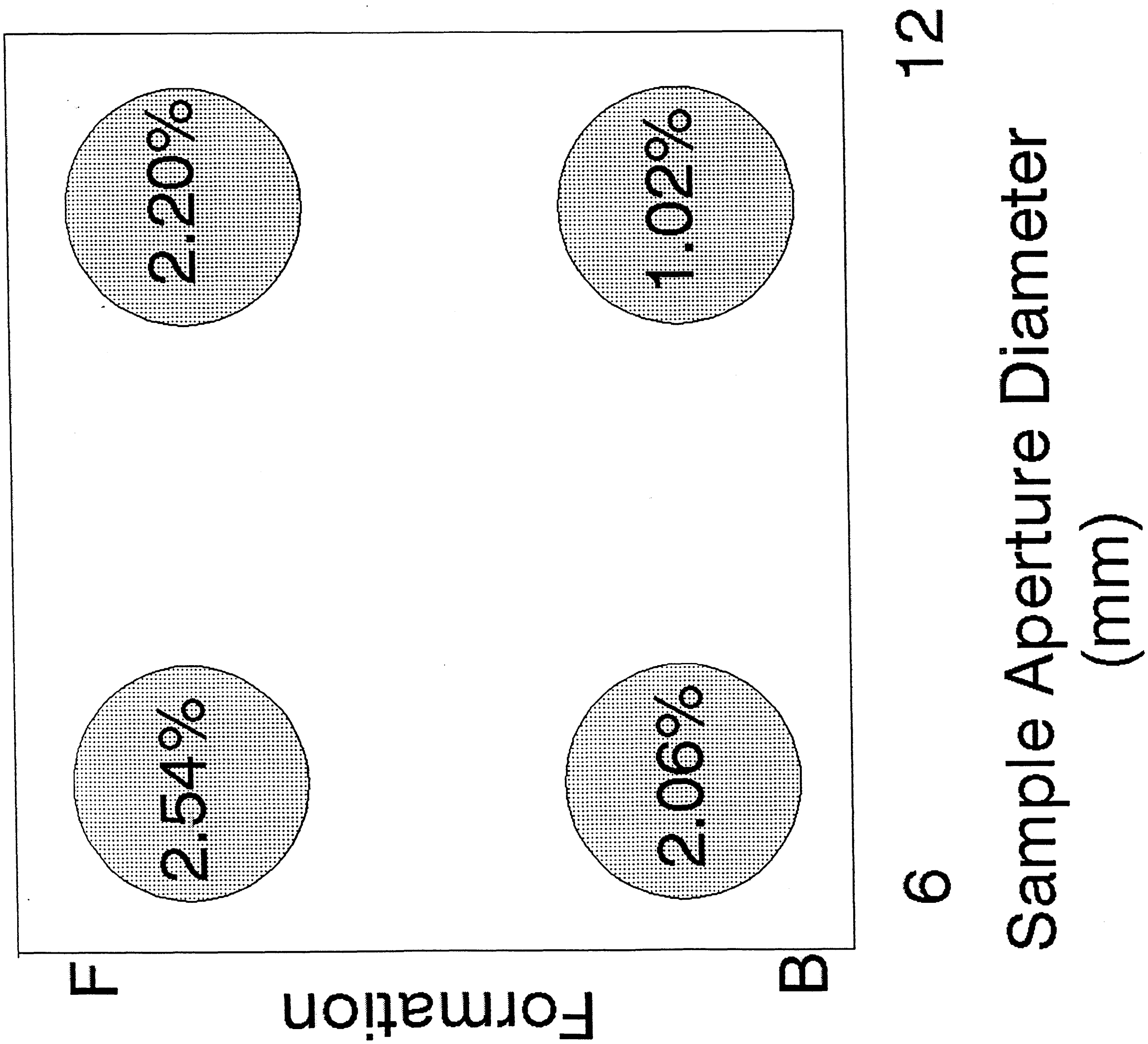
2.54%
2.20%
2.06%
1.02%
6
12
Sample Aperture Diameter
(mm)
F
B
Formation

Figure C

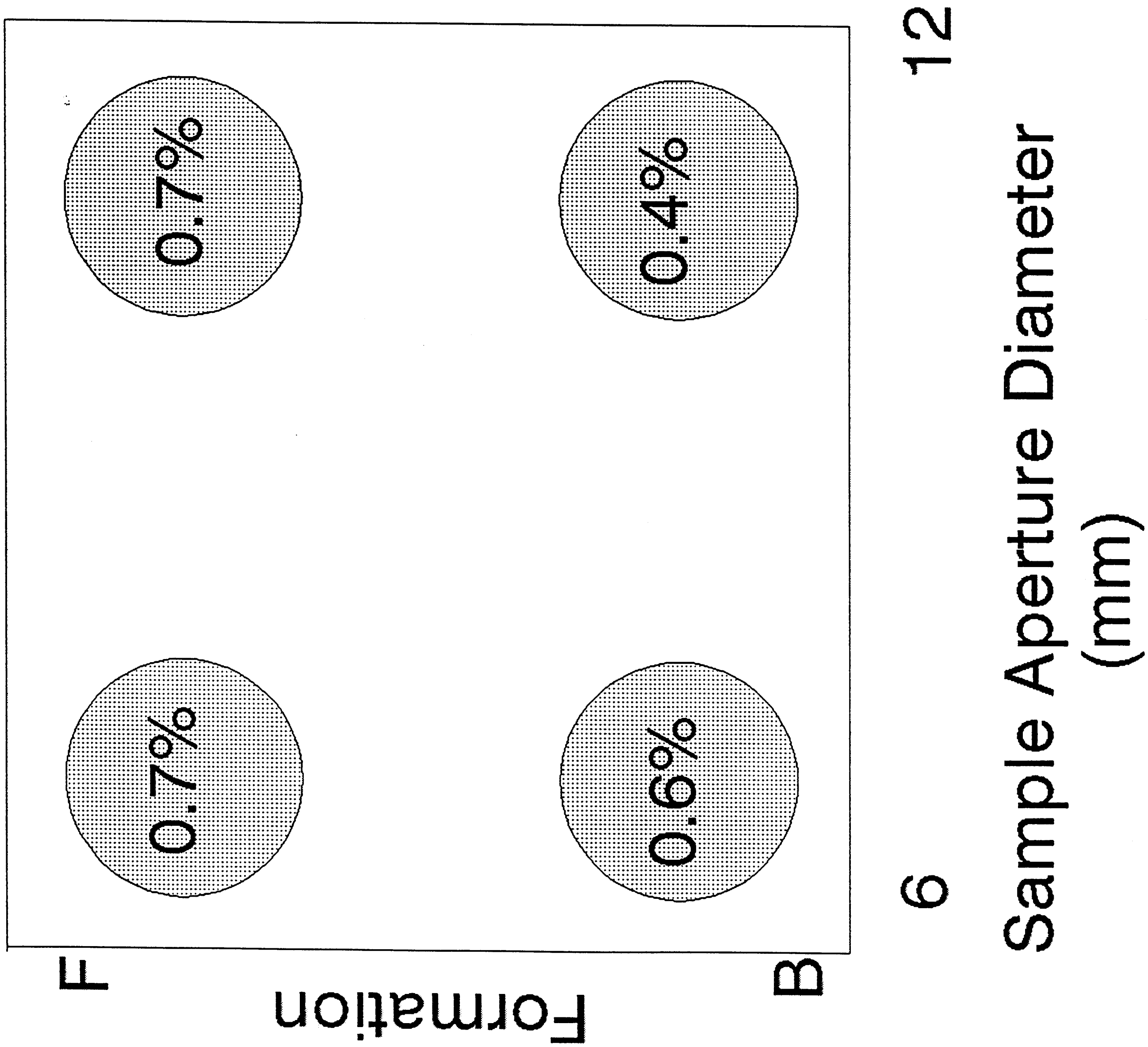

Figure D

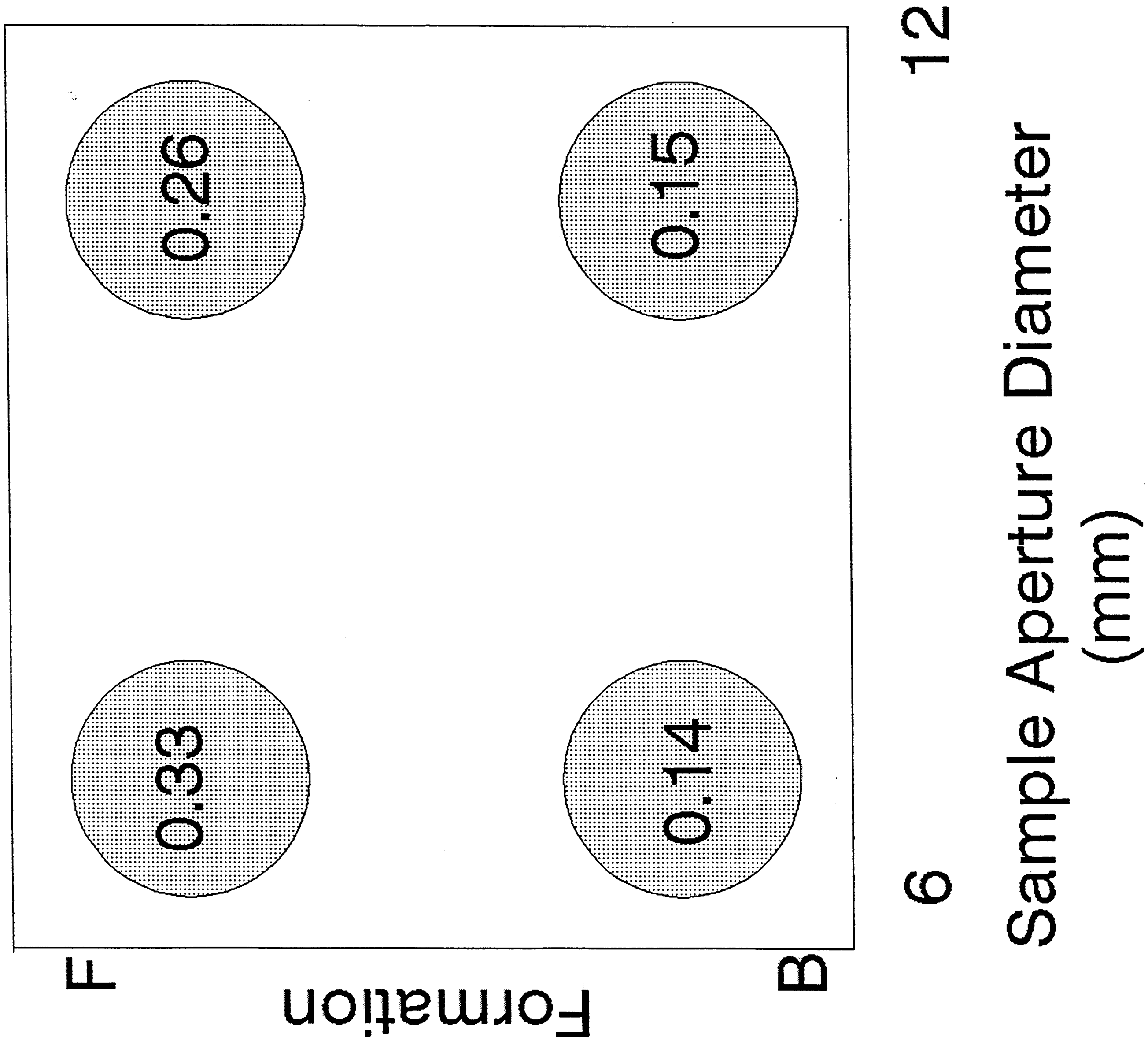
0.33
0.26
0.14
0.15
F
B
Formation
6
12
Sample Aperture Diameter
(mm)

Figure E

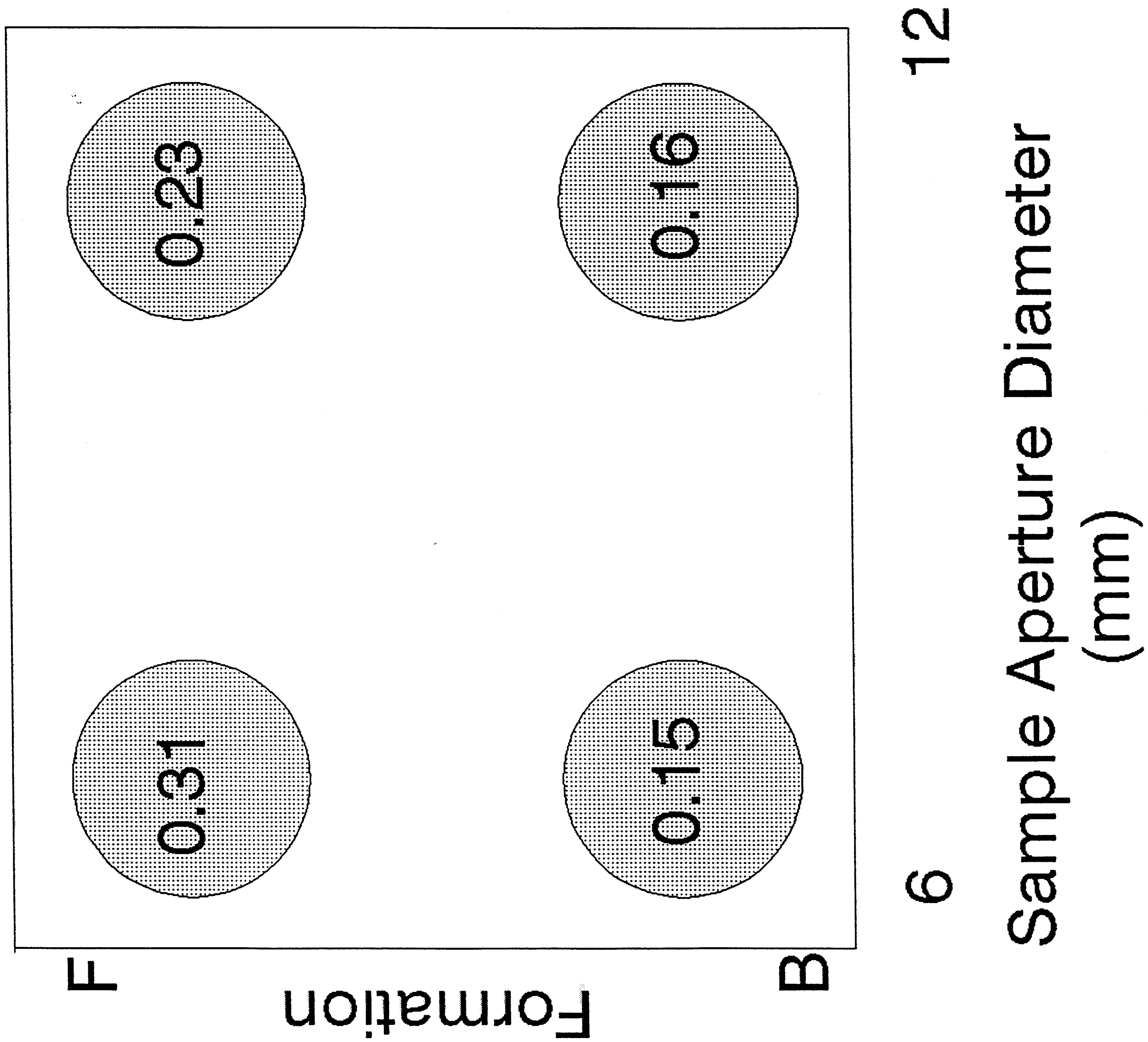
0.31
0.23
0.15
0.16
F
B
Formation
6
12
Sample Aperture Diameter
(mm)

Figure F

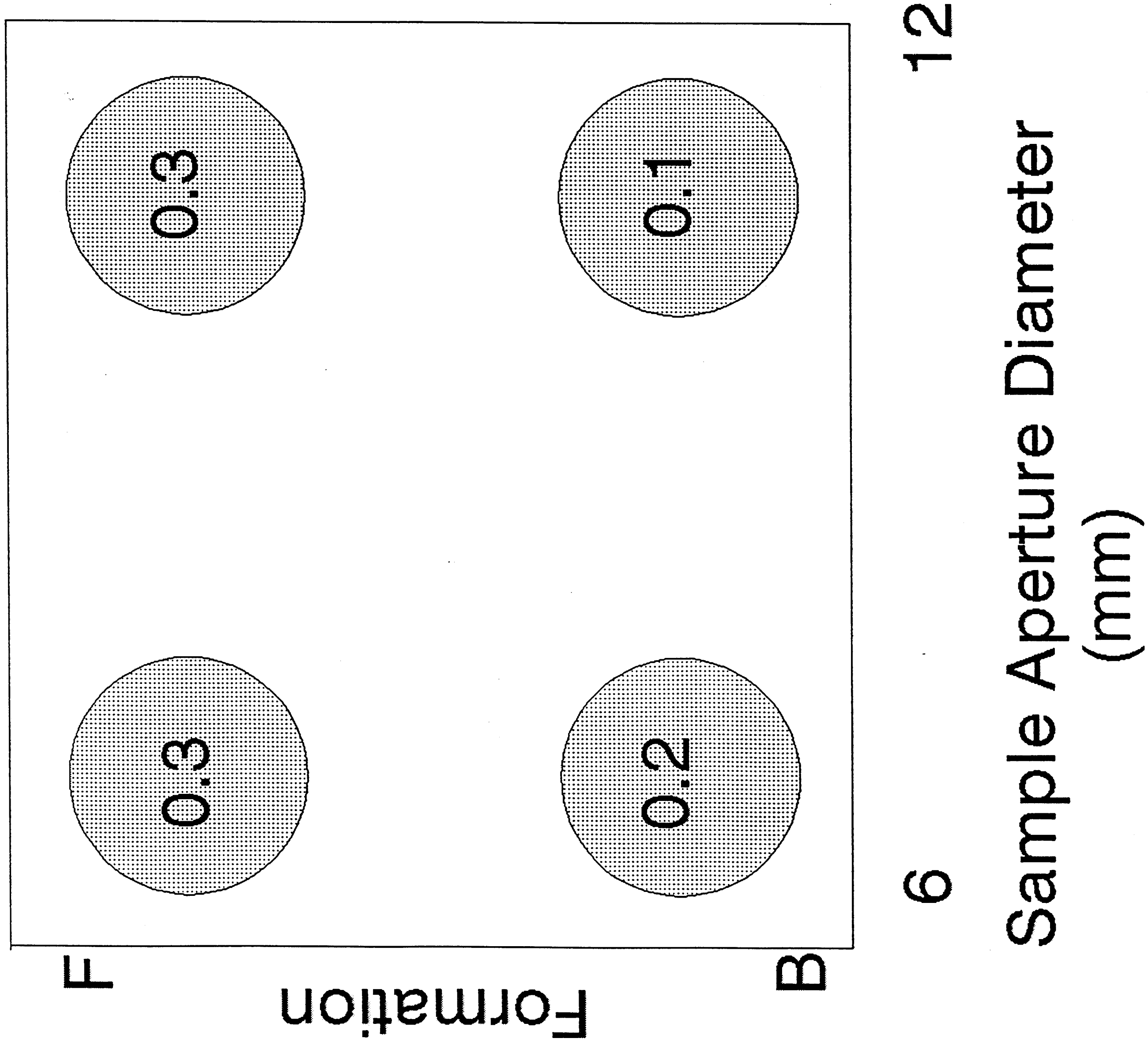

Figure G

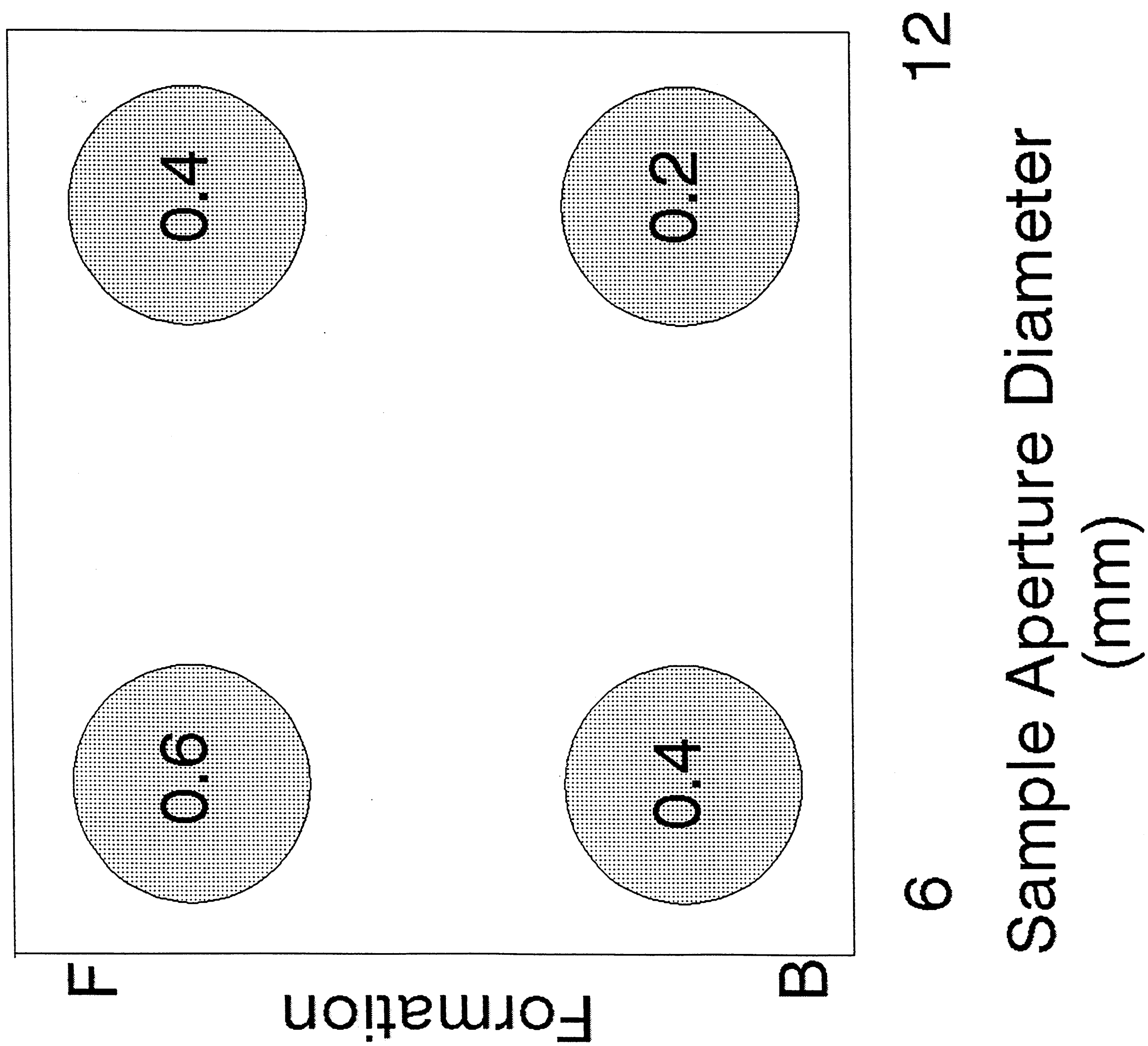

Figure H